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Lubrication

A Technical Publication Devoted to the Selection and Use of Lubricants

This Issue

CIRCULATING OILS

TEXACO
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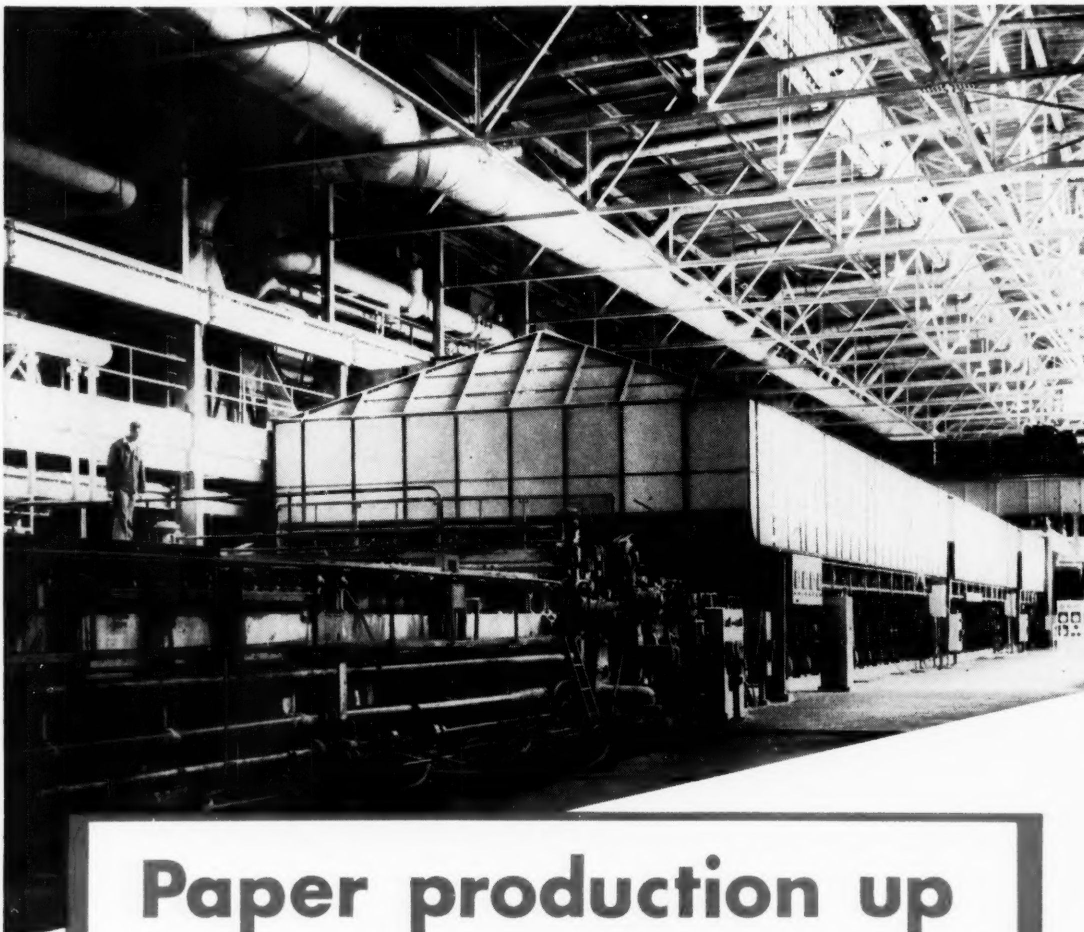

LUBRICATION

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CIRCULATING OILS

WHAT is a "Circulating Oil"? Most of us have grown accustomed to associate this term with something specific—a type of product having certain specified properties for use in large volume in some well-defined service, usually in a steel mill or paper mill, or a steam turbine power plant.

Webster defines "Circulate" as — "to move by a circuitous course back to the starting point, as the blood through the body." In its broadest sense, then, a circulating system, as applied to lubrication, is one in which the lubricant is moved from a reservoir through the equipment to be lubricated and then back to the reservoir. It is descriptive of a general method of applying the lubricant, rather than defining some specific service or application. With this concept, then, it is apparent that "circulating systems" are used to apply lubricants in a variety of different services. Automotive engines, aircraft engines, hydraulic systems, machine tools and turbines are all examples of types of service where circulating systems are used.

In this article, an attempt is made to distinguish between the various types of "Circulating Oils" by outlining the requirements of various systems wherein they are used. The terminology is used in its broadest sense and the article includes those oils usually referred to as crankcase oils. They, also, are used by means of recirculation from a sump or supply reservoir, and because of this, must possess properties characteristic of other circulating oils plus usually some additional very special ones of their own.

Continuing with this generalization, we can define a "circulating oil" as any lubricant which is used in a "circulating system". This definition, of course, immediately removes any identity with a specific service and merely indicates, in a broad sense, the manner in which it is applied. It should be readily apparent, then, that a circulating oil is not a single class of lubricant with certain well-defined properties. Rather, it includes a variety of products, each having the characteristics required to perform the service to which it will be put.

What are the lubrication requirements of the different types of applications and services in which circulating systems are used? What properties must the lubricants possess to satisfy best these various requirements? Are the requirements of any two applications so similar that a lubricant used in one could also be employed satisfactorily in the other? These and other questions come to mind when one thinks of comparing the circulating systems and oils among themselves. In the following discussion, various types of circulating systems are discussed, together with the properties of the lubricants needed to satisfy the requirements.

Before turning to the individual systems, mention

will be made of certain functions which are basic to all circulating systems.

1. A positive flow of clean oil of closely controlled viscosity and temperature is provided to the various points requiring lubrication and cooling.

2. Heat absorbed from the operating areas is released on the return cycle.

3. While part of the oil is moving to the areas requiring lubrication and cooling, part of the volume is available for a purification step to insure a clean oil supply. In this manner, accumulations of dirt, water and other foreign contaminants can be continually flushed out of the lubrication areas and removed from the system.

4. Oil is provided for the automatic supply of lubricant to a number of points at the same time under closely controlled conditions.

5. In some systems, the oil serves an additional function as a hydraulic fluid to actuate parts such as valve lifters, control mechanisms, and safety systems.

In a plant employing a wide variety of equipment, where each piece may be operating with a circulating oil system, a number of different oils might be required to best serve the lubrication requirements of all. Every effort, however, will usually be made to consolidate the number of lubricants employed, in an attempt to ease the storage and handling problem. Consolidation will often work to great advantage; however, extreme caution is advised to prevent over-consolidation and the use of the wrong oil. Every oil designed for a circulating system application has certain specific properties or characteristics; a knowledge of these, together with some knowledge of the operating conditions of the systems at hand, should be had before any consolidations or substitutions are made. It is good practice to consult first with the equipment manufacturer and oil supplier, after which the advantages to be gained must be weighed against any disadvantages that might be incurred.

"CIRCULATING OILS" FOR STEAM TURBINES

Today, the modern steam turbine has over 265,000 kilowatt capacity for stationary service and in excess of 55,000 horsepower for marine operations. Turbine rotors turn at 900 miles per hour peripheral speed; steam at 2,300 pounds pressure and 1,100°F. passes through the blades at a rate above 1,200 miles per hour. Quite a change from the days when a straight mineral oil was used to lubricate the 5,000 kilowatt units which were high for the time and operated with steam temperatures and pressures in the order of 500°F. and 200 p.s.i.g., respectively.

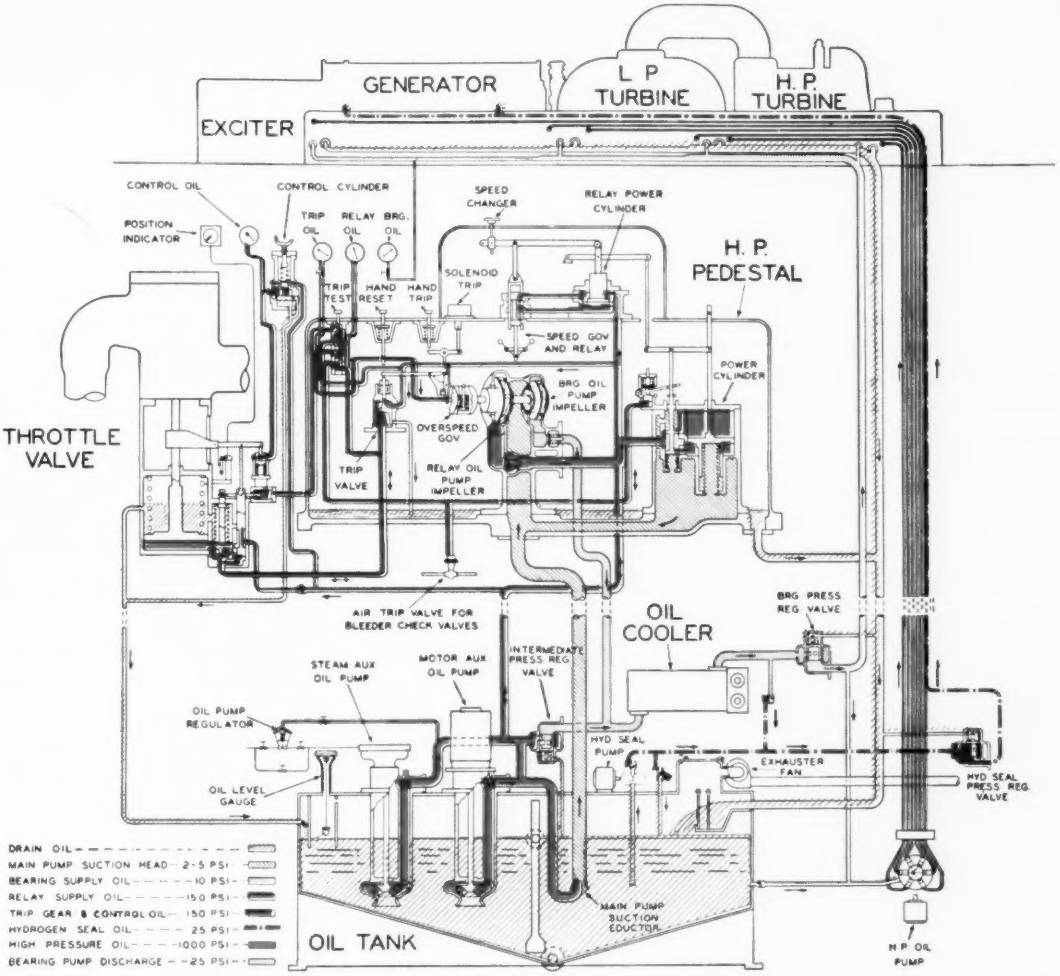
These rapid changes in turbine design and operating conditions brought with them added demands on the lubricating oils. These demands were met by modern advanced methods in refining and by use of specially tailored additives. Modern turbine oils have vastly increased service life and assure protection of the steam turbine for almost unlimited periods. They are designed to meet completely the conditions encountered in steam turbine operations and function in the full time role of lubricant, surface protector and coolant, as well as hydraulic and sealing mediums.

What is required of the steam turbine oil? The modern steam turbine oil must transmit the governor-varied impulses to the control mechanism, must properly lubricate its moving parts, and must keep the system free from rust and all deposits, as well as excessive entrained air, to assure full sensitivity at all times. The lubricant plays a vital part in the functioning of this intricate control system so necessary to the operation in meeting extraction steam demands and electrical load demands.

The oil must lubricate the bearings of the turbine and also generator bearings of a power unit and reduction gears where they are part of the mechanical system, as in marine service. Clean oil of proper viscosity for the specific system is essential. The viscosity must be high enough to assure adequate lubrication of all moving parts and yet sufficiently low to assure proper functioning of the control mechanism and low power losses. Viscosity Index in steam turbine service is of little importance.

The oil must serve as a *cooling medium* for the bearings and gears. Its flow rate, temperature at the inlet, viscosity and cleanliness are especially important in this regard. Heat is generated in the bearings and gears, due to shearing of the oil. The power loss is transformed into heat; for example, a 10-inch by 7-inch bearing, running at 3,600 r.p.m. with a 150 SSU at 100°F. oil entering the bearing at 120°F., will realize approximately a 12 kw. loss. The proper flow of oil of the correct viscosity and inlet temperature will control this factor and prevent an excessive temperature rise at the bearings. Oil temperature to the bearings is generally controlled at 110 to 120°F. and allowing for a 30 to 40°F. rise at the bearings, the temperature of the discharge oil will range from 140 to 160°F.

As a surface protectant, the oil must serve to protect all areas from the effects of water. Rust and corrosive products, aside from material damage, will cause plugging of the small oil lines, bringing oil starvation and faulty operation of control mechanisms. They will cause rapid wear of the moving parts and serve to catalyze the oxidation of the oil.



Courtesy of Allis-Chalmers Manufacturing Co.

Figure 1 — Details of a typical oiling system for a tandem-compound steam turbine.

They must be prevented from accumulating in the lubricating system and, if formed for any reason, must be readily removed by simple purification methods.

Some systems are equipped with hydrogen cooled generators, and the oil serves in a lesser function as the sealing medium to prevent hydrogen leakage.

Essential Properties

What properties must an oil have to meet these requirements?

1. *Correct initial viscosity* to comply with design. Turbine oil requirements will vary from 150 seconds Saybolt at 100°F. to 600 seconds, depending on the type and design of the unit.

2. Initially *clean and adaptable to fast cleaning methods* for quick removal of even traces of water and other contaminants. Water is the worst offender as a contaminant to the lubricating system of a steam turbine oil. It is the main cause of rust and corrosion. It tends to wash the inhibitors from the oil and produces emulsions with the oil in the presence of dirt or other foreign matter. Water also contributes directly and indirectly to the formation of oil sludge. It enters the lubricating system from the sealing steam glands, as condensation from the surrounding atmosphere and from leaks in the oil coolers. Fast removal of dirt and water and any resulting contaminants is imperative. To accomplish this, the oil must lend itself to easy purification means. It must, therefore, show fast water separating properties and little tendency to emulsify with water and foreign matter. For this reason, even small amounts of other additive oils such as emulsifying engine or detergent-dispersant motor oils, cannot generally be tolerated as contaminants in a steam turbine oil.

3. *Resistant to oxidation and sludging* under relatively mild conditions for extended periods. The formation and subsequent deposition of oxidation products can best be combatted through the use of oxidation inhibitors incorporated in the turbine oil. Such materials are now used extensively in steam turbine oils and, as such, are very effective in slowing down the rate of oxidation of the oil, even under severe steam turbine operating conditions and in the presence of foreign contaminants. Sludge is detrimental primarily because it clogs oil passages and governor parts. It may lead to corrosive attack on the bearing parts, and the components of the sludge will serve to catalyze further oxidation of the system oil.

4. *Protect against the formation of rust* should water enter the lubrication system. Modern turbine oils contain a rust inhibitor which is compatible with the other inhibitors used and the conditions existing in a steam turbine system.

It must not be corrosive to the turbine parts. Copper and steel components and babbitt bearings are the parts subject to attack.

5. *Highly resistant to foaming.* All oil retains air in solution. At atmospheric conditions, turbine oil will contain approximately 15 per cent by volume of air. During operation, air is mixed with the oil in a number of ways. The main source of excessive air entrainment, however, is at the bearings. A vacuum exists in a portion of the periphery of most bearings, a feature designed to prevent oil leakage. Some designs or improper adjustments may cause excessive accumulations of air and result in a foaming condition. Excessive foaming can result in faulty operation of the entire system if the design is not such as to provide a sufficient rest for foam breakage and air release. Modern turbine oils are designed for rapid vapor release and low foaming tendency. Anti-foam agents are often employed to improve this characteristic.

With the use of specially refined selected base stocks in conjunction with a number of additive materials, modern steam turbine oils will give many years performance under normal operating conditions. Under different conditions, relatively short life may be realized.

Yes, steam turbine oils are of a special high quality level designed for use in steam turbine systems employing from only a few to thousands of gallons where the requirements are exacting but well defined. They are used extensively also in hydraulic applications, in some paper machine applications and other fields where the requirements are such that these oils fit the mold. In some other circulating oil applications, the characteristics do not fit the requirements, and consequently other oils are not only better suited to the job but are essential.

"CIRCULATING OILS" FOR RECIPROCATING AUTOMOTIVE ENGINES

The complexity of the modern automotive engine continually is being increased in the interest of

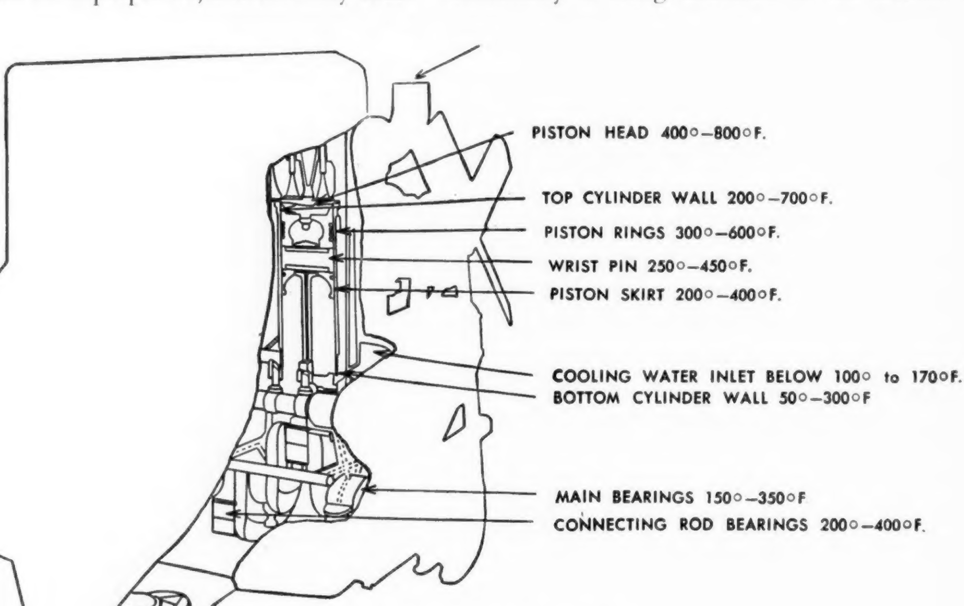
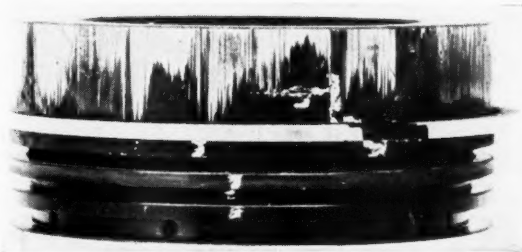
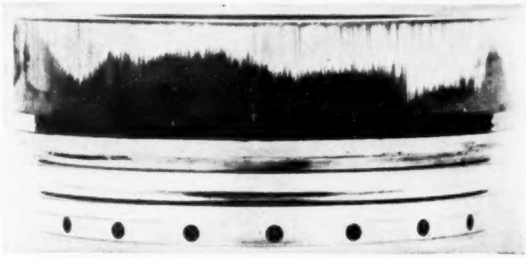


Figure 2 — Average temperatures at points where lubrication is important within a modern heavy duty automotive type engine.



A. Base Oil.



B. Base Oil plus a Detergent Additive.

Figure 3 — Effect of Detergent Additive on Ring Land Area Cleanliness — Note Stuck Ring in A. All Rings Free in B.

compactness, improved efficiency and ever higher power output. As the engines become more complex, their sensitivity to lubricants also grows.

The circulating oil, in addition to its use as a lubricant, also acts as a cooling and heat transfer medium, a sealing agent and hydraulic oil. The following operational conditions are encountered:

Modern engines are called upon to start at temperatures as low as $-30°$F. and to operate in atmospheric temperatures of above 100°F. The points of application may vary from well below 100°F. in the sump to above 700°F. on the top cylinder walls. The bulk oil temperature during operation will vary but normally will run between 130 - 160°F.

Driving conditions range from stop-and-go urban travel, with associated crankcase dilution, to continuous high speed turnpike cruising with associated higher temperatures. The loads imposed, as well as the speeds demanded, vary continuously. Atmospheric conditions encountered from hour-to-hour are rarely the same.

With fuel dilution, encountered through faulty carburetion, low temperature starting or continuous low temperature operation, come the contaminants associated with the fuel and its combustion—water, lead components, and fuel combustion products. The presence of these, together with dirt entering through the air intake, wear particles from the engine, etc., all tend to cause oxidation of the oil, especially at the points of high temperature contact, and lead to the formation of engine sludges and deposits. The accumulation on engine surfaces lead to further operational difficulties such as stuck rings, valves and ruined bearings and journals.

Today, the requirements placed upon circulating oils by automotive type engines probably are more severe than are found in any other form of service. To enable the oil to satisfy these requirements, it is necessary that it be of a specially selected and refined quality and suitably responsive to a variety of additive materials, each of which is incorporated to perform particular functions in creating the oil characteristics desired and proven necessary.

Essential Properties

Viscosities normally range from an SAE5W (approximately 130 seconds Saybolt at 100°F.) to an SAE60 (approximately 1,700 seconds Saybolt at 100°F.) for heavy duty hot operation.

To satisfy the demands for low temperature starting and normal temperature operation, a high viscosity index oil of 100 and above is required. Thus the viscosity will be low enough to enable starting and provide lubrication at low temperatures and high enough at normal operating temperatures to give satisfactory lubrication. Viscosity index improvers are added to produce the desired level.

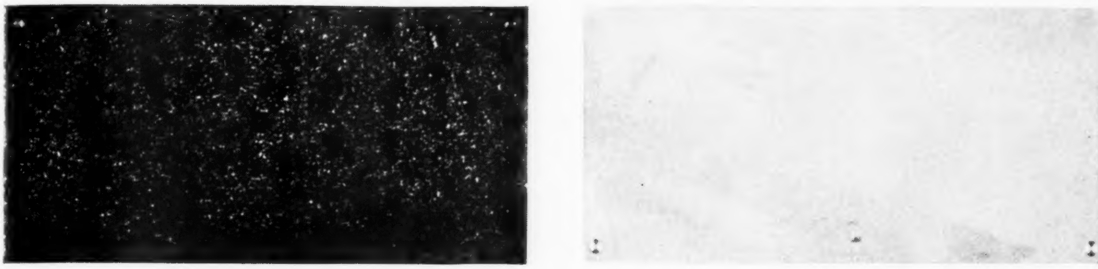
To enable starting and lubrication at low winter temperatures, a modern automotive oil must be substantially low in pour point. If the oil is not fluid, it cannot be delivered to the vital engine areas by the oil pump. To obtain a satisfactory operating level, pour point depressant additives are usually used.

Detergency as related to motor oils may be defined as the ability of the motor oil to keep engine surfaces clean through the removal of deposits. Dispersancy, on the other hand, is the ability to keep these same materials uniformly suspended throughout the oil. A high detergent-dispersant level is a much desired requirement of modern automotive oils to prevent deposit build-up on critical parts, to prevent re-deposition in localized sections with resulting plugging of the oil screen or oil passageways, and to facilitate removal of contaminants through periodic oil drains. These characteristics can be further appreciated when it is realized that the filtration which can be afforded within the limits of compactness and mobility is rarely adequate.

A high degree of oxidation stability is required to prevent the rapid formation of corrosive acids, lacquers and sludge, especially under the conditions found in automotive service. Such contaminants, when exposed to high temperatures, tend to form lacquer, a hard, dry, lustrous oil-insoluble deposit. In addition, the same materials that form lacquer

ADDITIVES COMMONLY USED IN MODERN AUTOMOTIVE LUBRICATING OILS

Purpose	*Types of Compounds Used*	*Reasons for Use*	*Mechanism of Action*
Anti-oxidants or Oxidation Inhibitors	Organic compounds containing sulfur, phosphorus or nitrogen such as organic amines, sulfides, hydroxy sulfides, phenols. Metals like tin, zinc, or barium often incorporated.	To prevent varnish and sludge accumulations on engine parts. To prevent corrosion of alloy bearings.	Decreases amount of oxygen taken up by the oil thereby reducing formation of acidic bodies. Additive generally oxidizes in preference to oil.
Anti-corrosives Corrosion Preventatives or Catalyst "Poisons"	Organic compounds containing active sulfur, phosphorus or nitrogen such as organic sulfides, phosphites, metal salts of thiophosphoric acid, and sulfurized waxes.	To prevent failure of alloy bearings by corrosive action. To prevent corrosive attack on other metal surfaces.	Inhibits oxidation so that no acidic bodies are formed or enables a protective film to form on bearing or other metal surfaces. Chemical film formation on metal surfaces decreases catalytic oxidation of the oil.
Detergents	Metallo- organic compounds such as phosphates, phenolates, alcoholates. High molecular weight soaps containing metals like magnesium, barium and tin.	To keep engine surfaces clean and prevent deposits of sludge of all types.	By chemical reaction or oxidation direction, oil soluble oxidation products are prevented from becoming insoluble and depositing on various engine parts.
Dispersants	Metallo-organic compounds such as naphthenates and sulfonates. Organic salts containing metals, like calcium, cobalt and strontium.	To keep potential sludge forming insolubles in suspension to prevent their depositing on engine parts.	Agglomeration of fuel soot and insoluble oil decomposition products is prevented by breakdown into finely divided state. In colloidal form contaminating particles remain suspended in oil.
Extreme Pressure Agents	Phosphorus compounds like tricresyl phosphate, sulfurized lard oil, halogenated compounds. Lead soaps such as lead naphthenate.	To prevent unnecessary wear of moving parts as well as scuffing or scoring.	By chemical reaction film is formed on metal surfaces which prevents welding or seizure when lubricating oil film is ruptured.
Rust Preventives	Amines, fatty oils and certain fatty acids. Halogenated derivatives of certain fatty acids. Sulfonates.	To prevent rust in new and overhauled engines during storage or shipment.	Preferential wetting of metal surfaces through added adhesiveness.
Pour Point Depressants	High molecular weight condensation products, such as phenols condensed with chlorinated wax. Methacrylate polymers.	To lower pour point of lubricating oils.	Wax crystals in oil coated to prevent growth and oil absorption at reduced temperatures.
Viscosity Index Improvers	Polymerized olefins or iso-olefins. Butyl polymers, cellulose esters, hydrogenated rubber.	To lower rate of change of viscosity with temperature.	Improvers are less affected by temperature change than oil. They raise viscosity at 200°F. more in proportion than at 100°F.
Foam Inhibitors	Silicones.	To prevent formation of stable foam.	Enables foam to break up quickly and disappear.



Regular Grade Motor Oil. Premium Heavy Duty Motor Oil.

Figure 4 — Difference in Degree of Rust Protection Afforded by a Regular and Heavy Duty Motor Oil (Modified AN-VV-C-576B Humidity Cabinet Rusting Test).

under high temperature conditions may coagulate with carbon, oil, water and foreign material in the crankcase to evolve a gray or black muddy mixture called sludge. Additives are used to inhibit against initial oxidation and to act as catalyst poisons for those metals tending to accelerate oxidation of the oil.

Whenever an engine is stopped and allowed to sit for even a relatively short period of time, the oil film, which normally separates parts moving relative to each other, will rupture, and metal-to-metal contact will result. In addition, operation under heavy loads or under conditions imposing abnormally high localized pressures will contribute to break-down of this film. Since operation with metal-to-metal contact for even very short periods will lead to extensive damage of the parts involved, it is imperative that the film strength of the oil be enhanced and that the metal surfaces be protected with a chemical reaction coating in the event that the film becomes ruptured.

When engines are new or newly overhauled and before they have been placed in service, the wrist pins, crankshaft bearing surfaces, and cylinder walls are particularly susceptible to attack by rust. During extended periods of non-operation even with used engines, droplets of water from the atmosphere tend to condense on the engine surfaces, penetrate the oil layer, and attack the ferrous parts. Since a relatively small amount of rust can lead to extensive engine deterioration, it is important that the vital parts be protected from attack. Usually, a straight mineral oil will provide adequate protection under normal operating conditions. In some cases, however, excessive condensation is sufficient to exceed the rust prevention capabilities. To protect under stop-and-go type of driving in cold weather and during extended periods of storage, the heavy duty oils contain appreciable amounts of rust preventives.

"CIRCULATING OILS" FOR STEEL MILLS

Steel mill machinery is very heavy and rugged and at the same time must lend itself to precision performance, especially in steel rolling operations where gauge tolerances are measured to a few thousandths of an inch. It often operates under extremely adverse conditions which is one big reason why circulating oil systems are employed. The heavy contamination encountered necessitates constant attention to the oil in an effort to keep it in as clean condition as possible.

Some of the different applications of circulating oil systems in steel mill operations are described below.

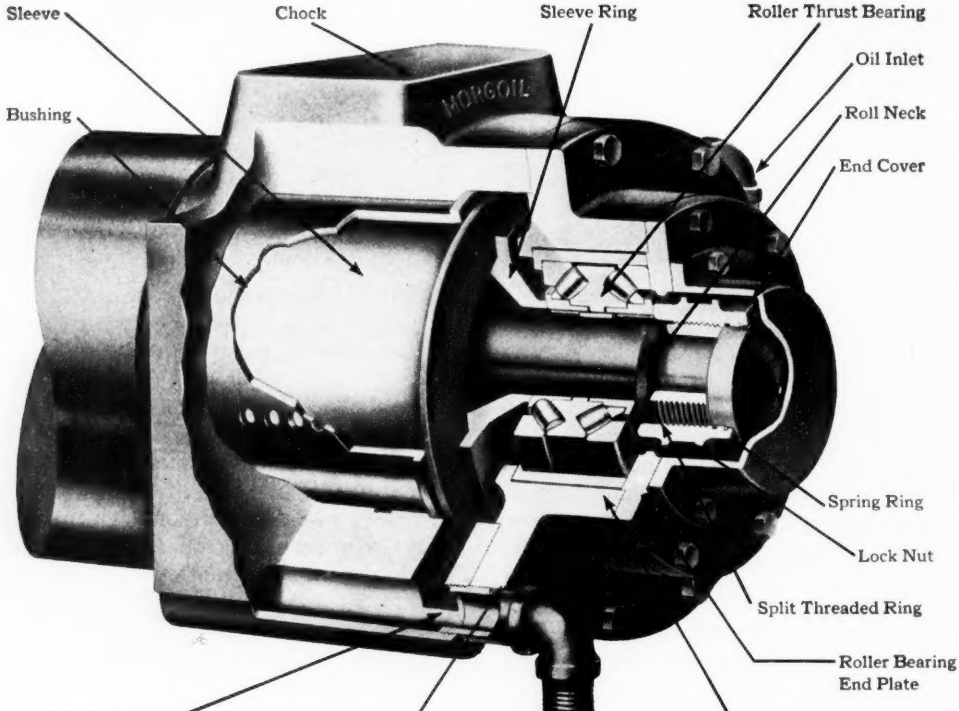
Oil Film Type Roll Neck Bearings On Backup Rolls

This equipment performs the very heavy duty service in steel mills, since the backup rolls carry most of the load. The operating conditions are severe, and at the same time, the lubricating system is subjected to heavy contamination from water, mill scale, roll oil and dirt.

The heavy loads involved necessitate the use of high viscosity oils; the particular viscosity required is usually specified by the bearing manufacturer and is calculated on the basis of speed, temperature and load conditions involved.

Heavy contamination of the circulating oil is a most severe problem. In hot rolling of steel where large volumes of water are sprayed on the rolls for cooling, water contamination of the oil past the bearing seals may be especially heavy. High pressure water sprays are also used for the purpose of cleaning mill scale and dirt from the steel stock before it enters the roll stand, creating an additional source of contamination. In cold rolling operations, contamination with roll oils also constitutes a problem. The roll oils with their fatty oil content play havoc with the water separating properties of the circulating oil.

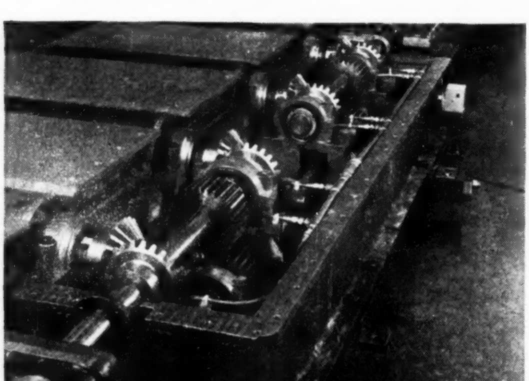
Any mineral oil will oxidize gradually in service, especially when in intimate contact at high temperatures with air, water and fine mill scale catalytic particles. The result is a gradual increase in acidic



Courtesy of Morgan Construction Co.

Figure 5 — Cutaway View of Precision Sleeve Type Backup Roll Neck Bearing Equipped with a Roller Thrust Unit. Straight Mineral Circulating Oil Used for Lubrication.

and oxidation products as well as the formation of small amounts of metallic soaps. These materials may eventually precipitate out of the oil and together with water and mill scale form a sludge-like accumulation. The presence of these contaminants cannot be tolerated and effective means for their removal must be employed.



Courtesy of Farrell-Birmingham Company, Inc.

Figure 6 — Section of a Roller Table with Cover Removed to Show Gearing Arrangement. Close proximity to Red Hot Steel Creates Adverse Temperature Conditions. Mild E. P. Type Lubricants are usually used for Gears and Bearings.

Most mills are equipped to handle bulk purification of oils as well as means for continual removal of water and contaminants during operation. Although most of the water and contaminants settle out in the sump tank and are either drawn off regularly or removed by centrifuging or pressure filtering, the contamination content gradually builds up to a point where it is desirable to remove the oil from service for batch purification. This is possible where the two tank system is employed. Each tank has a capacity of from 5,000 to 10,000 gallons of oil which is alternated in service about every two weeks; one batch is being re-conditioned while the other is in use. This assures a standby supply of clean oil.

In hot rolling operations especially, where steel at 1800°F. and higher enters the rolls, heat of conduction and radiation raises the circulating oil temperature considerably. In this same operation where water and mill scale can find their way into the oil, these conditions will lead to relatively fast oxidation of oil where the stability characteristics are not sufficiently high.

Essential Properties

A satisfactory oil for use in the circulating oil system for the oil film-type roll neck bearings must therefore have the following properties:

The viscosity requirements usually fall within the range of 600 to 2500 seconds Saybolt at 100°F. and even higher in very slow speed bearings. The viscosity in service is controlled by the temperature. The bulk oil temperature on the return cycle is approximately 110-130°F., and the oil is cooled before re-circulation to approximately 100°F.

The new oil must possess excellent water separating properties and retain these properties during service. It should lend itself to large scale purification methods for removal of water, mill scale, dirt and sludge, as well as for separation of water and dirt from oil emulsions which may form during extended use under adverse conditions. The better the separating properties of the oil, the longer it can be continued in service and the easier it is to clean it up.

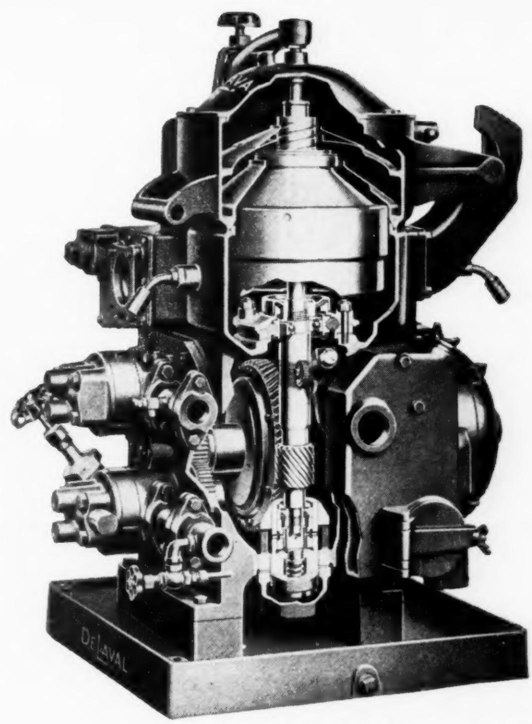
Enclosed Gears and Bearings on Mill Tables in Pinion Stands and Gear Reduction Sets

In these systems either one or two sump tanks are installed below the equipment level to permit gravity return. Water and mill scale are partially settled out by gravity, followed by either or both centrifuge treatment and pressure filtering. The oil is then passed to coolers to reduce the temperature of the oil to approximately 100°F. before it is returned to the feed part of the cycle. Size of tanks for handling these circulating oils may vary from 1000 to 12,000 gallons capacity depending on the number and size of the units to be served by the system.

Essential Properties

In order to function properly in these applications, the circulating oil should possess the following characteristics:

The high load carrying capacity requirements necessitate the use of EP additives. The additives used should not seriously detract from the other qualities, although some relaxation in water separating requirements must be tolerated. They must be also of such a nature that they are not removed from the oil during the purification step. In the mill table, line shaft and edger drive circulating systems, oils with viscosities ranging between 400 and 1400 seconds Saybolt at 100°F. are used. The lower viscosities are preferred where water separation is a problem and where oil lines are long and subjected to low temperature winter conditions. In pinion stand and reduction gear circulating systems, oils with viscosities ranging from 1500 to 3500 seconds Saybolt at 100°F. are used. The heavier



Courtesy of the De Laval Separator Company

Figure 7 — Cutaway View of a "Uni-Matic" Oil Purification Unit for Removing Water and Contaminants from Circulating Oils. It Consists of a Separator, Pumps, Heaters, Electrical Controls, and Auxiliary Equipment all compactly mounted on a Single Base.

grades are used normally on the pinion stands and the lighter grades in reduction gear sets.

Relatively fast separation from water, mill scale and dirt is important to prevent the formation of emulsions and sludge. The purification systems in use are extensive, and almost continuous purification is required to maintain the systems oil in a suitable condition and to prevent the formation of stable emulsions.

The higher the viscosity index (less change of viscosity with temperature) and the lower the pour point, the easier the starting at low temperatures following a shut-down and the better the lubrication under starting conditions.

Air entrained in the oil must be able to free itself rapidly during the rest period. The better the resistance to foaming, the better the operation under adverse conditions where higher than normal amounts of air become entrained.

The presence of mill scale, water and air at high temperatures in an environment of catalyzing metals such as copper, lead to relatively fast oxidation and deterioration of the oil unless it is of good oxidation stability. This property must be built in to give the desired service life.

In addition, a satisfactory oil should produce no

corrosion of the various system components, provide good adhesion to gears even in the presence of water and yield no separation during storage.

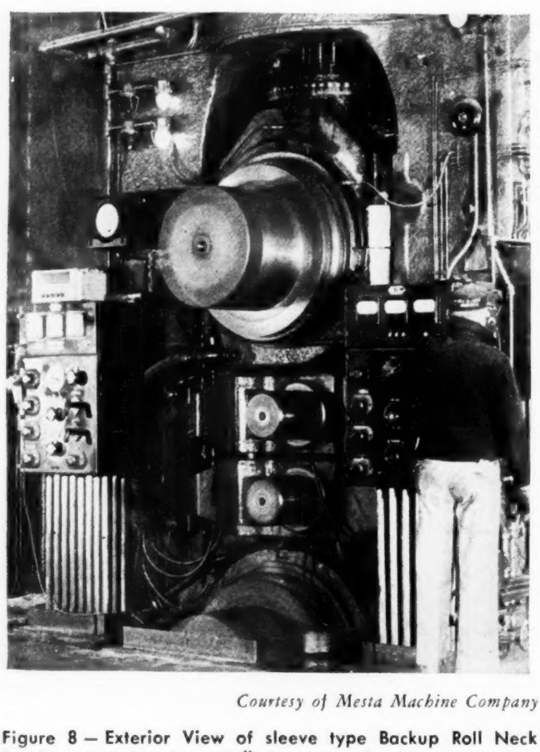
Steam Driven Blowing Engines

Straight mineral inexpensive red engine oils with viscosities ranging between 200 and 300 seconds Saybolt at 100°F. are used in circulating systems of steam driven blowing engines which supply immense volumes of air to blast furnaces. The oil lubricates guides, cross-heads, and fly wheel main bearings (plain type). The relatively mild conditions of operation permit the use of these inexpensive, less highly refined oils where highly special performance characteristics are not economically justified.

"CIRCULATING OILS" FOR AIRCRAFT ENGINES

In reciprocating aircraft engines of all sizes, the engine oil here again serves as a lubricant and coolant. In certain combinations of large engines and propellers, the engine oil is also a hydraulic fluid which varies the pitch of the propeller blades. These uses expose the oil to a variety of environmental factors which place severe demands on the lubricant.

The temperatures to which engine oil is exposed are probably the crucial factor as far as oil operation is concerned. Even in normal service, a wide temperature range is encountered. On one hand, peak surface temperatures as high as 500-600°F. are found on exhaust valve stems and guides. Other parts, such as pistons and cylinder walls, are not quite as hot, but the necessity for good high temperature oxidation stability is critical. Because of the large amounts of heat rejected to the oil, the temperature of the oil scavenged from the engine is as high as 240°F. On the other hand, the engine oil is also expected to give satisfactory engine operation at low temperatures which are experienced when the engine is started and operated under winter conditions. Overcoming the oil's viscous drag and obtaining adequate oil flow to bearings and other parts can pose quite a problem. Another low temperature effect occurs when the engine is operated at high altitudes, even in the summertime. Oil temperature in the propeller can drop as low as 20°F., and bulk oil temperatures in the external oil tanks which are used instead of integral crankcases can be in the range of 75 to 100°F. For satisfactory operation an aircraft engine oil, therefore, should exhibit the minimum possible change in viscosity over the engine temperature range.



Courtesy of Mesta Machine Company

Figure 8 — Exterior View of sleeve type Backup Roll Neck Bearings installed in a 56" Four-High Four Stand Tandem Cold Reduction Mill. Straight Mineral Circulating Oils are used for Lubrication.

A very important enviromental effect is oil contamination encountered in service. The contaminating materials are the result of fuel combustion. Incompletely oxidized hydrocarbons are formed under fuel-rich operating conditions which characterize take-off and climb operation. Tetraethyl lead reaction products are another major source of contamination. Both types of materials are carried into the oil by blow-by gases which find their way past piston rings, exhaust valve stems and through other necessary engine clearances. The engine oil must satisfactorily disperse and carry the finely divided lead compounds and must resist the deteriorating effects of all these contaminants which often have binding or resinous properties. Water, an inevitable combustion product, is absorbed by the oil and helps in the formation of lead sludges at low oil temperatures.

A factor which distinguishes aircraft engine lubrication systems from many other circulating systems is the penalty placed on both excess size and weight in aircraft operation. As a result, extensive and thorough oil filtration is not carried out on aircraft engines. Also, high flow rates are needed. These high flow rates, combined with excess volume scavenge pumps, can sometimes create foaming troubles. It should be pointed out here that the major portion of the "oil carried" is contained in a separate portion of the oil tank to make up oil burned by the engine. The significance of this oil consumption is demonstrated by the fact

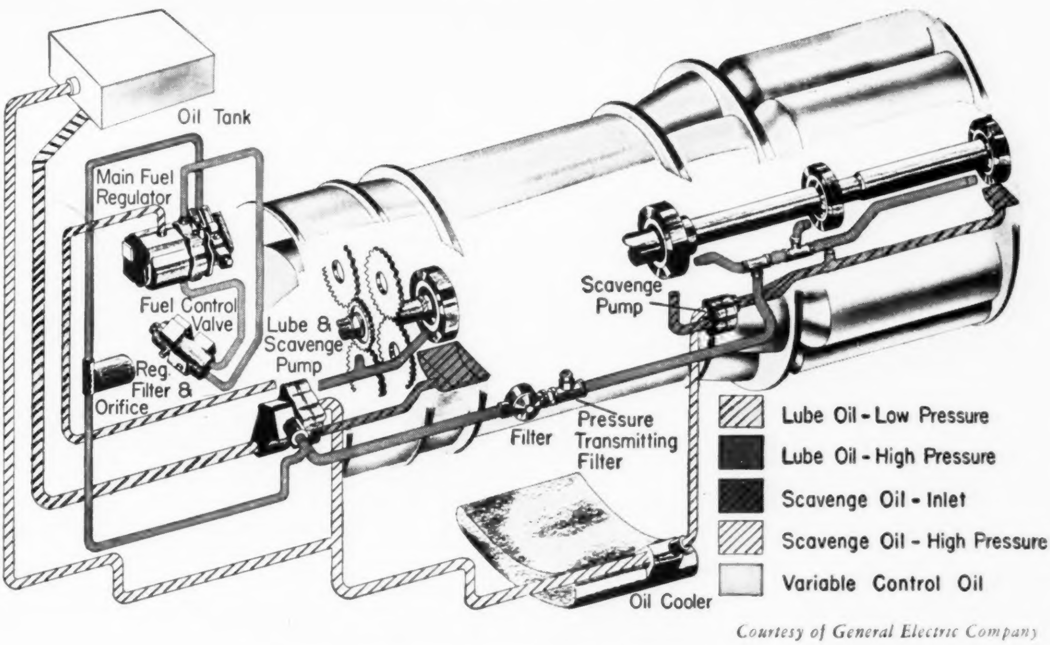


Figure 9 — Lubrication System of a J-47 Turbo-Jet Engine.

that the largest reciprocating engines consume about $1\frac{1}{2}$ gallons of oil per flying hour. Such high oil consumption leads to continual oil replenishment, which in turn reduces the frequency of oil drains to the point where today, in most engines, the oil is drained and replaced only at engine overhauls. High oil consumption also tends to discourage the use of very expensive lubricants unless they can extend parts life and improve engine reliability.

In the aircraft engine, the oil is used to lubricate all engine parts and accessories such as oil pumps and gear drives. The oil must maintain metal to metal separation and withstand high, vibrating loads in plain and rolling-contact bearings as well as in a large variety of high speed, highly loaded precision gears. The oil is also exposed to a variety of materials such as aluminum, magnesium, steel, bronze, silver and a number of other bearing materials. It cannot corrode any of these materials at their highest operating temperatures. It also should not attack various seal materials which are used in gaskets, seal rings and other applications.

Essential Properties

In answer to these challenges, a series of straight mineral oils has been developed which are made from selected crude stocks and are highly refined to have high oxidation stability and low deposit forming tendencies. They are of high viscosity index and low pour point. They are non-corrosive to the various materials found in aircraft engines and have high load carrying capacity. They resist the formation of lacquers and other materials which tend to block lubricating passages. They are, in short, one of the primary reasons for the existence and satisfactory performance of today's airline engines.

The use of additive-containing oils has led to tremendous improvement in different types of combustion engines. Their use in aircraft engines, however, has been limited by several critical problems. Many oil additives, when burned, form metallic oxides as ash. Because of the high oil consumption in an aircraft engine a considerable amount of ash can be deposited in the combustion chambers. Such deposits in an aircraft engine can be the cause of highly destructive preignition because of the high power output of these engines. Certain additives, when exposed to the high temperatures on exhaust valve stems and guides, are known to fuse into hard, lava-like materials which can result in valve sticking. Some additives, while improving oil performance in certain regards, may be corrosive to bearing or valve guide materials. It is clear, therefore, that the development of additive oils for aircraft engines presents considerable problems. In cases where such oils are being used, it has been found desirable to change normal engine clearances so that the maximum benefit of the oil's performance could be obtained. Progress is being made, but considering the safety aspects involved, it must be at a conservative rate.

TABLE I

Oil Flow Data on Some Current Aircraft Reciprocating Engine Models

Engine Displacement Cu. In.	1820	1830	2000	2800	3350[a]	4360
Normal Take-Off Rating, HP	1525	1200	1450	2100	3250	3250
RPM	2800	2725	2700	2800	2900	2700
Normal Rated-Power, HP	1275	1050	1200	1800	2600	2800
RPM	2500	2550	2550	2600	2600	2550
Oil Flow at Rated RPM Approx. Gals. per Min.	18	14	19	29	47	50
Typical Volume of Oil Carried in System, Gallons	17	17	28	32[b] 20[c]	40	32

[a] Turbo-Compound. [b] Four-engine aircraft. [c] Twin-engine aircraft.

Gas Turbine Aircraft Engines

Although the oil in a gas turbine engine performs the same general functions as in a reciprocating engine, a dissimilar enviroment has resulted in the development of radically different oils. Until now, "jet engines" have been used mostly for military operation where low temperature starting ability and high engine output are of primary importance. These requirements are conflicting as far as oil characteristics are concerned. For successful low temperature starts, the oil must not exert more than a certain viscous drag on bearings and other components and therefore cannot have more than a defined maximum viscosity at temperature such as −65°F. These circumstances lead to the use of a fairly light oil. The high power output of these engines, on the other hand, requires that large amounts of power be transmitted through small gears operating at high speeds. Turboprops in particular are critical in this regard, as high load-carrying capacity of the oil will allow reduction of gear sizes and will result in important weight savings. The high power output of these engines also results in bearing temperatures up to 500°F. and bulk oil temperatures of 300°F. Obviously the oil must possess good oxidation stability and low volatility at such temperatures. These requirements, together with the load-carrying factor, favor a heavy oil which still has a fairly high viscosity at high temperatures.

In the jet engine lubricating system, the oil contacts and should not affect a large variety of materials, such as different high temperature steels, bronze, silver, aluminum, magnesium, titanium and lead, many of them at high temperatures. The oil also contacts different types of flexible materials such as seals and hoses which it is not expected to attack. Certain environmental factors are less severe for gas turbine oils than for reciprocating engine oils. While hydrolytic stability is required, contamination by products of combustion is minor or nonexistent. Except for the oil required for rotating seal lubrication, no oil consumption occurs.

Essential Properties

Since the requirements of earlier and many current gas turbine engines were not as severe as outlined above, such engines have been satisfactorily lubricated with light mineral oils which had the required low temperature viscosities such as 10,000 centistokes maximum at −65°F. Turboprop gear requirements, however, started the development of synthetic lubricants which, while they had low viscosities, acquired high load carrying capacities through the use of E. P. additives. The advent of high bearing temperatures hastened development of these oils which are superior in oxidation resistance and volatility characteristics to the light mineral oils.

At present, oils meeting two specifications are in use. The U. S. Military specification requires engine starting at −65°F., while the British specification requires starting at −40°F. The British specification, however, has a higher gear load requirement. Requirements of future commercial aircraft appear to favor the lower viscosity U. S. Military type of oil for pure jet engines, while the higher viscosity British-type oil is preferred for turboprop engines.

It is interesting to note that stationary, large gas turbines for power plant or shipboard use, where size restrictions do not exist and where plenty of

Figure 10 — Bearing just as Removed from Paper Machine After 12 Month Service Using a Detergent Type Oil.

cooling air or liquid is available, are very satisfactorily lubricated with mineral oils.

"CIRCULATING OILS" FOR PAPER MACHINES

The circulating oil systems for modern high speed paper machines are very similar to those in other industrial operations in that they supply the required amount of clean lubricant to bearings and gears to provide satisfactory lubrication and insure continuous operation.

There are three essentially different designs of paper machines and their use is dependent primarily on the type of material being manufactured. These are the Fourdrinier, "Yankee", and Cylinder machines. The Fourdrinier machines greatly outnumber the other types since they are used in the manufacture of all newsprint and kraft papers. The operating conditions and bearing design for the three types of units differ only slightly, and consequently their lubrication by circulating oil systems can be considered the same. The Fourdrinier, being the most popular, is used as an example.

The circulating oil system of a modern paper machine consists of a clean oil tank from which the oil is continually pumped under pressure (approximately 35 p.s.i.) through a header along each side of the dryer sections from which it is fed at a controlled rate to the individual bearings and gears. The oil overflows the bearings and gears into a return oil header which returns it to the central supply tanks where it is settled and filtered prior to recirculation. In addition to lubricating the dryer section, this oil may also be used in the power input gear cases and the Calendar stack to which it is fed through separate circulating lines.

The circulating oil used in paper machines not only serves as a lubricant but is also required to cool the bearings, protect them from corrosion and keep them free of deposits. The relative importance of these four functions is dependent upon the operating condition of each machine. The older slow speed machines, operating at low steam pressures, were lubricated satisfactorily with straight mineral oils. Oil oxidation occurred and it was normal practice to suspend operations periodically to pull the bearings and remove the carbonaceous deposits. Extended down-time periods lacked the significance that they do in today's economy. The use of higher dryer steam pressures to increase drying rates, larger machines and the high value assessed against down-time has dictated the use of circulating oils designed for this service and which guarantee maximum hours of operation.

Essential Properties

Since oils in this service are subjected to relatively high temperatures, high loads and heavy water contamination, a lubricant must have several necessary facets to perform satisfactorily. The prime requirements are as follows:

The *oxidation stability* of circulating oils in this service is of paramount importance since large volumes are involved and frequent replacement due to oxidation, which impairs the usefulness of the oil, is uneconomical. There are several factors that should be considered in order to insure optimum service performance in respect to oxidation.

The original selection of an oil having good oxidation resistance is mandatory. The petroleum research chemists in their development of oils for specific purposes have recognized for years that oil oxidizes in service and that the extent of oxidation is dependent upon the service conditions to which it is exposed. In order to improve the resistance to oxidation of normally refined lubricating oils,

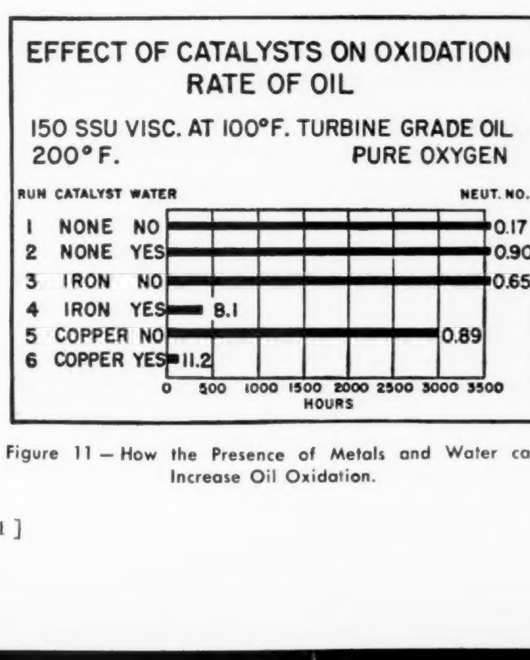


Figure 11 — How the Presence of Metals and Water can Increase Oil Oxidation.

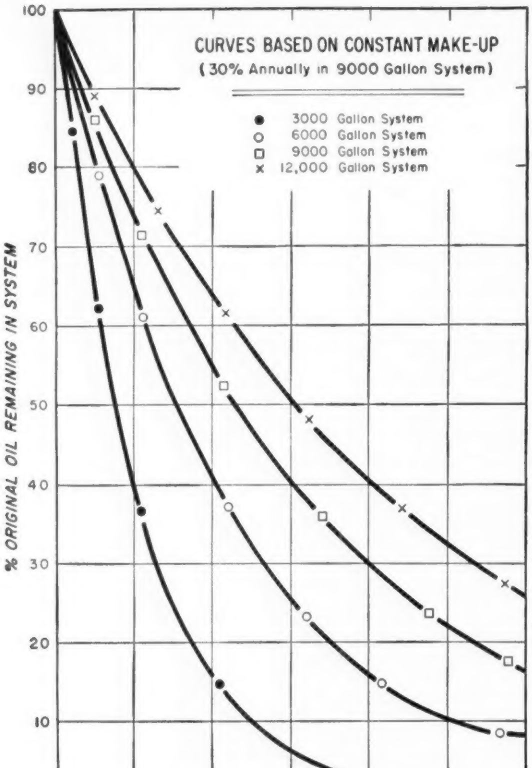


Figure 12 — Rate of Replacement of Original Charge of Oil in Lubricating Systems of Paper Machines.

oxidation inhibitors are added. The inhibitor used must be selected to retard oxidation under the conditions to which the oil is to be exposed and at the same time have no detrimental effect on other essential properties of the oil.

The temperature to which a paper machine circulating oil is exposed is the most important single factor affecting its oxidation. Bulk oil temperatures in the circulating system are not nearly as significant as the bearing surface temperatures to which the oil is exposed in thin films under conditions conducive to oxidation. The oil passing through the larger self aligning double roller bearings is carried around the bearing races by the rollers in thin films constantly in contact with moisture saturated air. This is especially true in the drive side bearings which are mounted on hollow journals through which high pressure steam is fed to the dryers and condensate returned.

There are no reliable data available as to bearing surface temperatures but these will vary over a considerable range from newsprint and tissue machines operating at low steam pressures to those on Kraft machines where 150 p.s.i. steam pressure and 50°F. superheat may be used. It is reasonable to assume that bearing temperatures increase with steam pressures at an increasing differential due to radiation losses. Since oil oxidation is a chemical reaction and increases rapidly with temperature, it is readily apparent that more heat resistant circulating oils are required in the Kraft machines than the newsprint and tissue units.

A second factor which increases oil oxidation is the presence of catalysts. Certain metals, especially copper, accelerate oxidation and consequently should be held to a minimum in circulating oil systems. Copper tubing which can be easily manipulated to make oil feeder and return lines to the bearings has been used in this service with detrimental results. The acidic constituents in the oil after a period of use react with the copper to form oil soluble copper soaps which hasten further oil oxidation. Finely divided iron wear particles from gears and other rubbing mechanical parts has an analogous effect. This catalytic effect of copper and iron is further accelerated by the presence of moisture.

A third factor having a definite effect on the service life of a circulating oil is the volume of oil in the circulating oil system and the rate of make-up oil required monthly due to losses resulting from leakage which is inherent in all machines to a widely varying degree. The volumes vary from 1,000 to over 14,000 gallons, and the annual rate of make-up ranges from 14 per cent to well over 100 per cent of the volume in the system. It is obvious that the oil in those machines having high make-up rates will be slower to show the effects of oxidation under given operating conditions than those with low make-up rates due to the increased quantities of new oil that is required to maintain the original volume. Since the volume of make-up for any machine is relatively constant, it is further evident that the oil in those units having small oil systems is replaced faster than in those having larger volumes.

The differential gears and transfer cases as well as the calendar stacks are normally lubricated by the same system used for the dryer bearings. The former offers little difficulty in respect to lubrication. The calendar stacks are not critical in respect to lubrication of the anti-friction bearings on the rolls. They may be the source of frequent trouble, however, depending on whether or not the king roll bearing is shrouded to prevent water gaining entrance to the circulating oil. If this occurs it is well to install a small circulating system designed solely for this unit.

One of the by-products of oil oxidation is carbon or carbonaceous material which is variable in na-

ture, depending on the conditions under which it is formed. When straight refined mineral oils were used in paper machine circulating oil systems operating at moderate steam pressures, carbonaceous material was deposited in the bearings and oil circulating lines to the extent that extended shut-downs were required to remove these deposits manually. This down-time was anticipated to the same extent as the time required for wire change.

Detergent-dispersant type oils were introduced into this service prior to the period of increased steam pressures to eliminate the carbonaceous deposits and minimize the extensive time required for their removal. These oils contain additives which hold carbon and carbonaceous material in suspension in the oil and thereby prevent their settling and accumulating in the bearings. They served their purpose exceptionally well. They not only eliminated the necessity of manually cleaning bearings at the semi-annual shut-downs but were introduced into dirty machines for the specific purpose of removing accumulated deposits from previously used non-detergent oils. The efficiency of this operation is dependent upon the detergency level of the new oil and the nature of the deposits on the bearings. With the high value set for hourly down-time on modern high speed paper machines, the elimination of pulling and manually cleaning bearings is of prime importance.

Paper machines have kept pace with the general trend of increased size of other industrial equipment as they are much larger, heavier and faster than similar units built a decade ago. Greater sheet widths and higher steam pressures have imposed greater loads at higher temperatures on the dryer bearing oil films and have necessitated a change in the general thinking as to value of load carrying capacity of oils under operating conditions. This was forcibly brought to the attention of the industry during the period of transition to high temperatures. A large number of bearing failures occurred on high temperature machines lubricated with straight mineral or turbine type oils. An investigation of this epidemic of failures revealed that failure could be attributed to decreased load carrying capacity of these oils at the high temperatures. This investigation further disclosed that this property of detergent type oils did not depreciate to the extent of the others with increased temperatures and that bearing failures did not occur in units using this type of circulating oil.

The presence of water and its effect on lubricants is a factor which must be considered in the lubrication of practically every piece of processing equipment in a paper mill. This is especially true

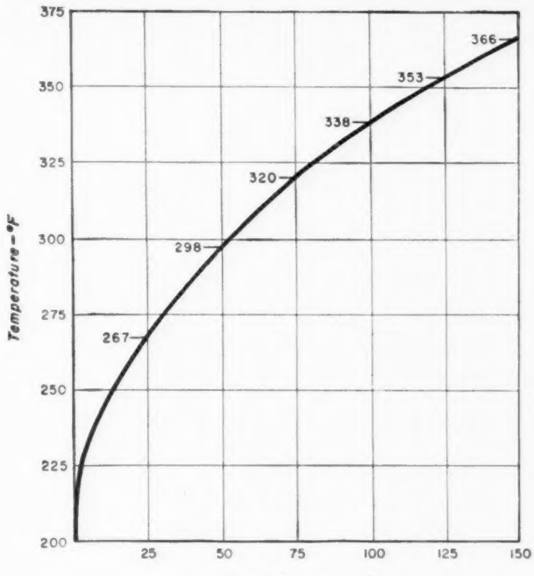


Figure 13 — Temperature of Saturated Steam.

in the case of the circulating oils where large volumes are involved and where water contamination occurs due to faulty steam seals and condensation. The effect of water on detergent type circulating oils is of special significance since a large measure of their satisfactory performance is due to additives which are water sensitive to varying degrees. The oil supplier must select additives for paper machine circulating oil with considerable care to insure satisfactory performance under optimum operating conditions and insure against water leaching the additive from the oil or forming stable emulsions with the oil. The machine operators should take whatever steps are necessary to minimize water contamination.

The water sensitivity of detergent type oils presents problems but at the same time has advantages, since it is this property that enables the oil to prevent moisture collecting on the bearing surfaces and causing corrosion. A properly designed detergent oil will allow no rusting in the bearing and other parts of the lubricating system.

The viscosity of paper machine circulating oils ranges from 600 - 1,100 seconds Saybolt at 100°F., with the higher viscosity products normally used in the high temperature machines. There are a number of advantages of using oils having viscosities toward the minimum of the above range. The lower viscosity oils permit a higher circulation rate and provide greater cooling to the bearings. They also permit faster separation of contaminating water and thereby minimize corrosion possibilities.

TABLE II

Summary of Required Properties for Some Circulating Oils*

			Steel Mills			Aircraft		
	Steam Turbines	Automotive Engines	Roll-Neck Bearings	Enclosed Gears and Bearings	Blower Engines	Reciprocating	Gas Turbines	Paper Mill
Demulsibility	√		√	√				√
Detergency		√						√
Dispersion		√						√
Oxidation Resistance	√	√		√		√	√	√
Rust Protection	√	√						√
Foam Resistance	√			√	NONE			
High V. I.		√		√		√	√	
Low Pour Pt.		√				√	√	
E. P. Properties		√		√			√	
Low Wear at Boundary Lubrication		√		√		√	√	√

*Ordinarily obtained by the use of additives.

SUMMARY

A wide variety of types and formulations of "circulating oils" are available. In any given circulating oil system, definite and usually well defined properties of the oil are required to provide satisfactory operation. Once these are established, the proper oil can be selected. Whether it be a motor oil, a turbine oil, a straight mineral or a highly fortified additive product, is in itself not important; if it possesses the characteristics and properties dictated by the service, it can be used satisfactorily in the equipment's circulating oil system. Should it lack one or more of these properties, certainly less satisfactory performance can be anticipated and under some conditions, wasteful and costly results will be realized.

A Summary Table is included to bring out more forcibly the similarity between circulating oils for differing services and to emphasize the properties needed for those services.

With the combined knowledge of the equipment manufacturer, the equipment user, and the oil supplier, selection can be made of the proper products which will provide satisfactory service in each of the various circulating systems, only a few of which have been discussed in this article.

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